Application of Numerical Modelling to a Case of Compaction Driven Dolomitization: a Jurassic Paleohigh in Southern Alps, Italy*

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Abstract

The dolomitization in a carbonate platform can occur at different times and in different diagenetic; the application of reactive transport modelling may help to select the model that best honours the mass balance, kinetic and thermodynamic constrains.

The subject of this study is an application of the reactive transport modelling (RTM) software 'Toughreact' (Xu, 2004) coupled with a basin simulator (SEBE3, Eni proprietary) in a case study of dolomitization interpreted as due to flux of basin waters into paleohigh carbonates in shallow burial realm (Jurassic of the Southern Alps). The collected data and approach are part of a R&D Eni proprietary project. The aim of the simulation was to strengthen the conceptual interpretation and to give insights on the distribution of dolomitization in the subsurface using a mass balance approach.

The modelling process was subdivided into parts; at first the reconstruction of the compaction fluid flow and its funneling into the permeable paleohigh was calculated in a 3D setting, then the RTM was applied. Sensitivities on the dolomite precipitation kinetics and on the diagenetic fluid composition suggested that the dolomitization was an efficient process even at the low temperatures, and the main difference regards the process rate. The permeability is the most important factor influencing the fluid flow and consequently the dolomitization.

In terms of mass balance the simulations indicate that the paleohigh isolated in deep pelagic basin seem to be the best site for replacement pervasive dolomitization because the high amount of compaction fluids with respect to the paleohigh rock volume.
The combined use of basin simulator and RTM has proven to be a powerful methodology that helps in verifying the model reliability and provides insights on the volumetric distribution of the diagenetic products.

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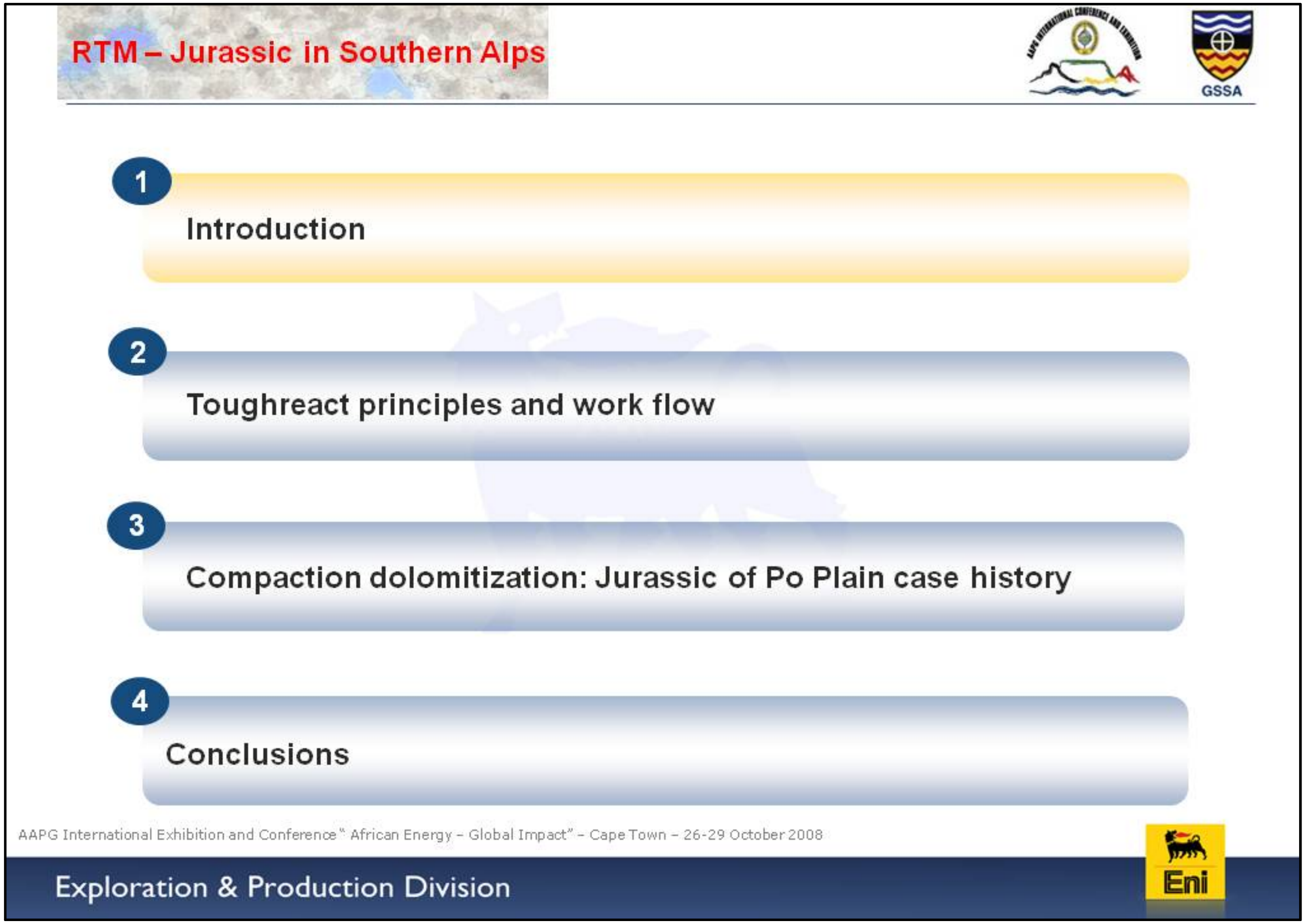
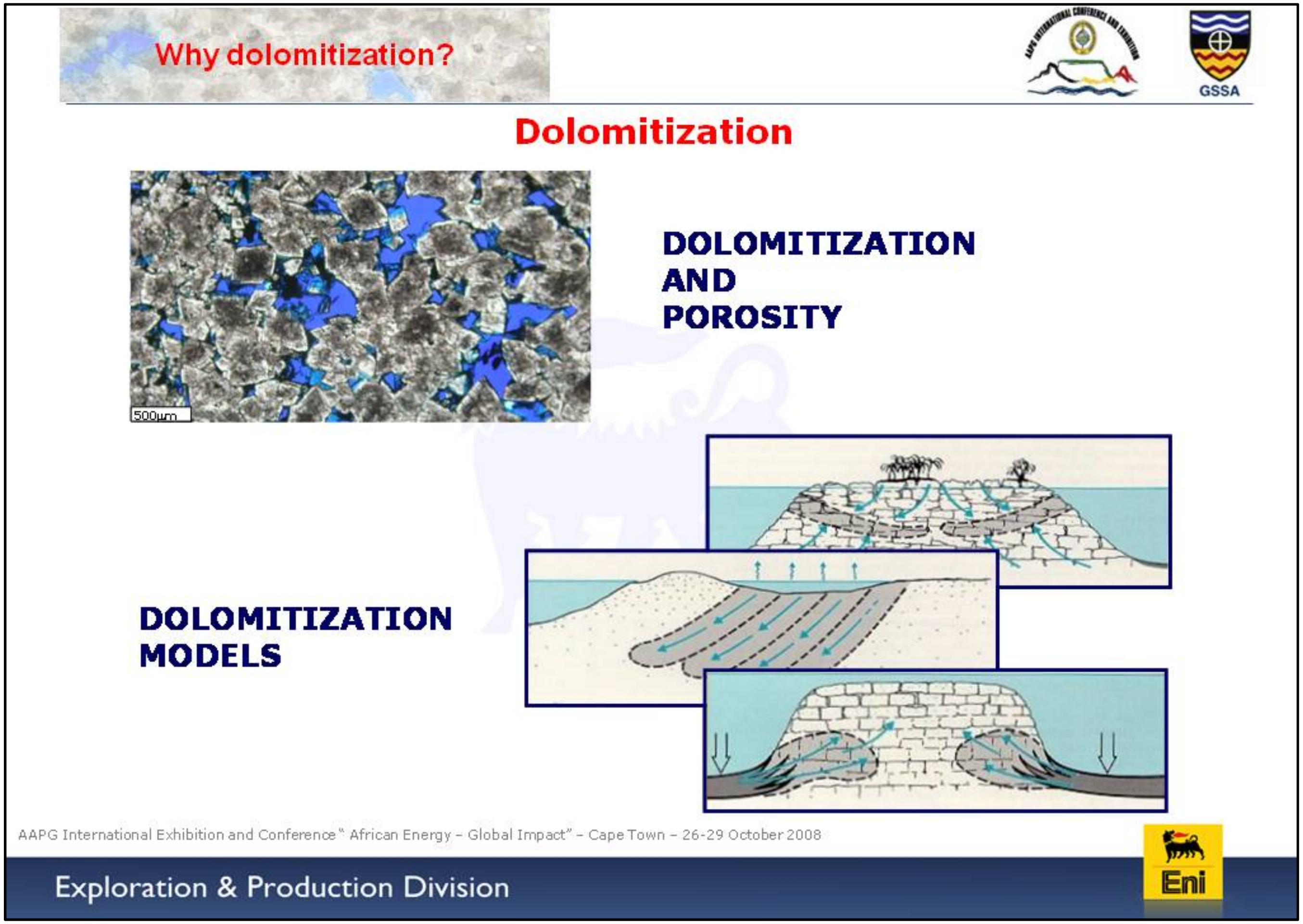
Ronchi Paola*, Consonni A.*, Battistelli A.**, Geloni C.**,
Gianelli G.***, Grigo D.* and Ortenzi A.* (speaker)
Cape Town – 28 october 2008



Notes by Presenter:

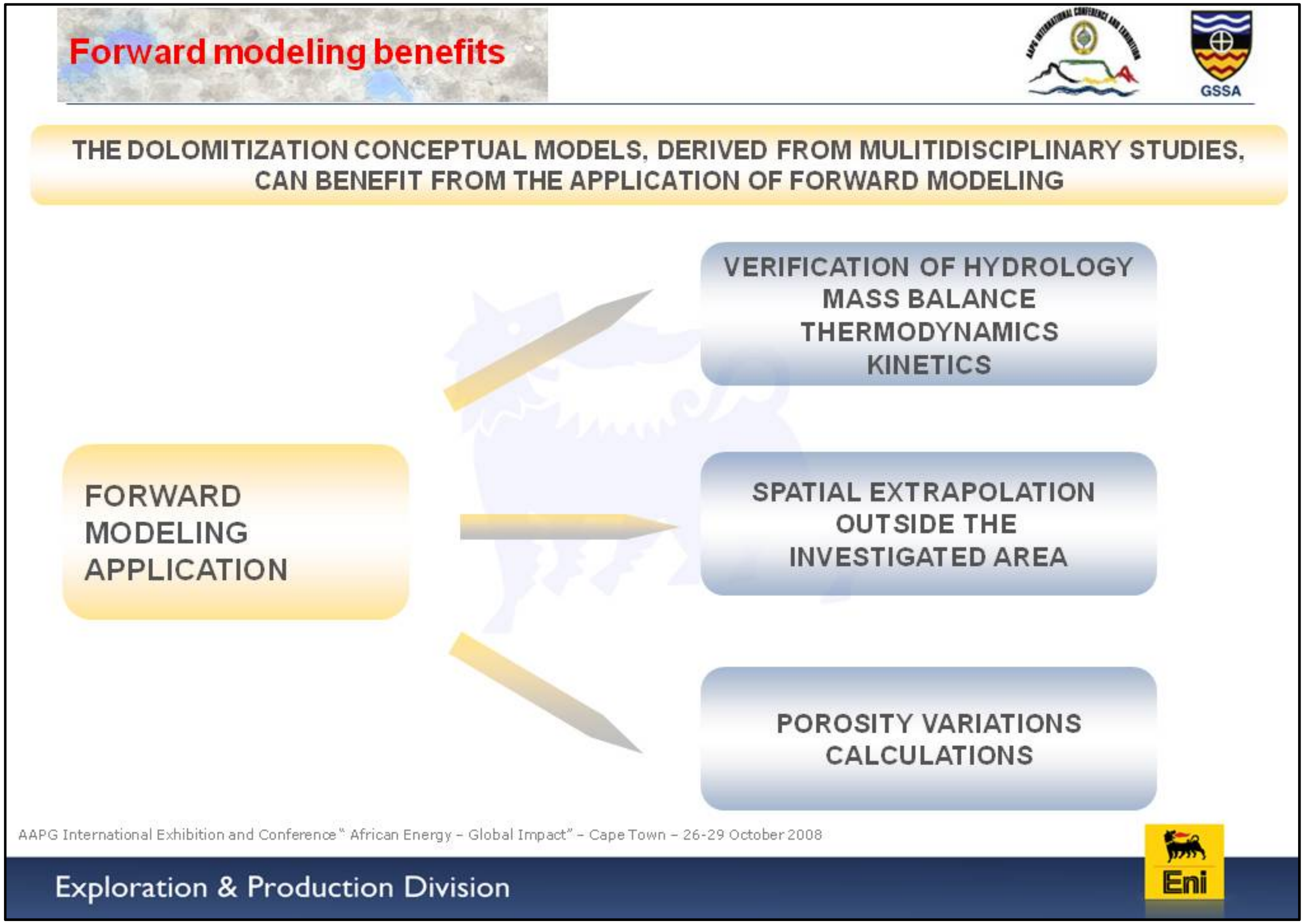
As you can see, I've divided my presentation into 5 main points:

- Firstly an introduction about the dolomitization and diagenesis problem in carbonate hydrocarbon reservoirs.
- Secondly few words about the Reactive Transport Modelling software and its application.
- Then we'll see 2 case histories of different dolomitization models: the first case deals with the compaction dolomitization.
- The second case deals with the convection and reflux dolomitization models.
- Finally the conclusions.



Notes by Presenter:

The dolomitization process usually increases the petrophysical properties of a carbonate rock; dolomitized bodies therefore can constitute good hydrocarbon reservoir. (This is the main reason of the efforts in study the dolomitization process by the oil companies.) The dolomitization in a carbonate platform can occur at different times and in different diagenetic environments from synsedimentary to deep burial settings; each model gives rise to a particular geometry of dolomite body; therefore the correct interpretation of the dolomitization model helps in the prediction of the distribution of the potential dolomite reservoir.



Notes by Presenter:

The benefits of the numerical Modelling application in diagenetic studies vary according to the diagenetic issue.

- First of all the numerical simulation is a valuable tool to assess the conceptual model in terms of hydrology mass balance, kinetics and thermodynamics
- Furthermore we can try to predict the lateral extension of the process and its products outside the investigated area, particularly valuable in the subsurface
- Finally the numerical modelling calculates the variations in porosity associated with the diagenetic process.

Content

1. Introduction
2. Toughreact principles and work flow
3. Compaction dolomitization: Jurassic of Po Plain case history
4. Other applications and conclusions

Notes by Presenter:
Reactive Transport Modeling software toughreact.

Toughreact

TOUGHREACT

Transport Of Unsaturated Groundwater and Heat

Earth Sciences Division of Lawrence Berkeley National Laboratory (LBNL) Berkeley, CA (USA)

Calculation of rock/water system evolution through the simulation of:

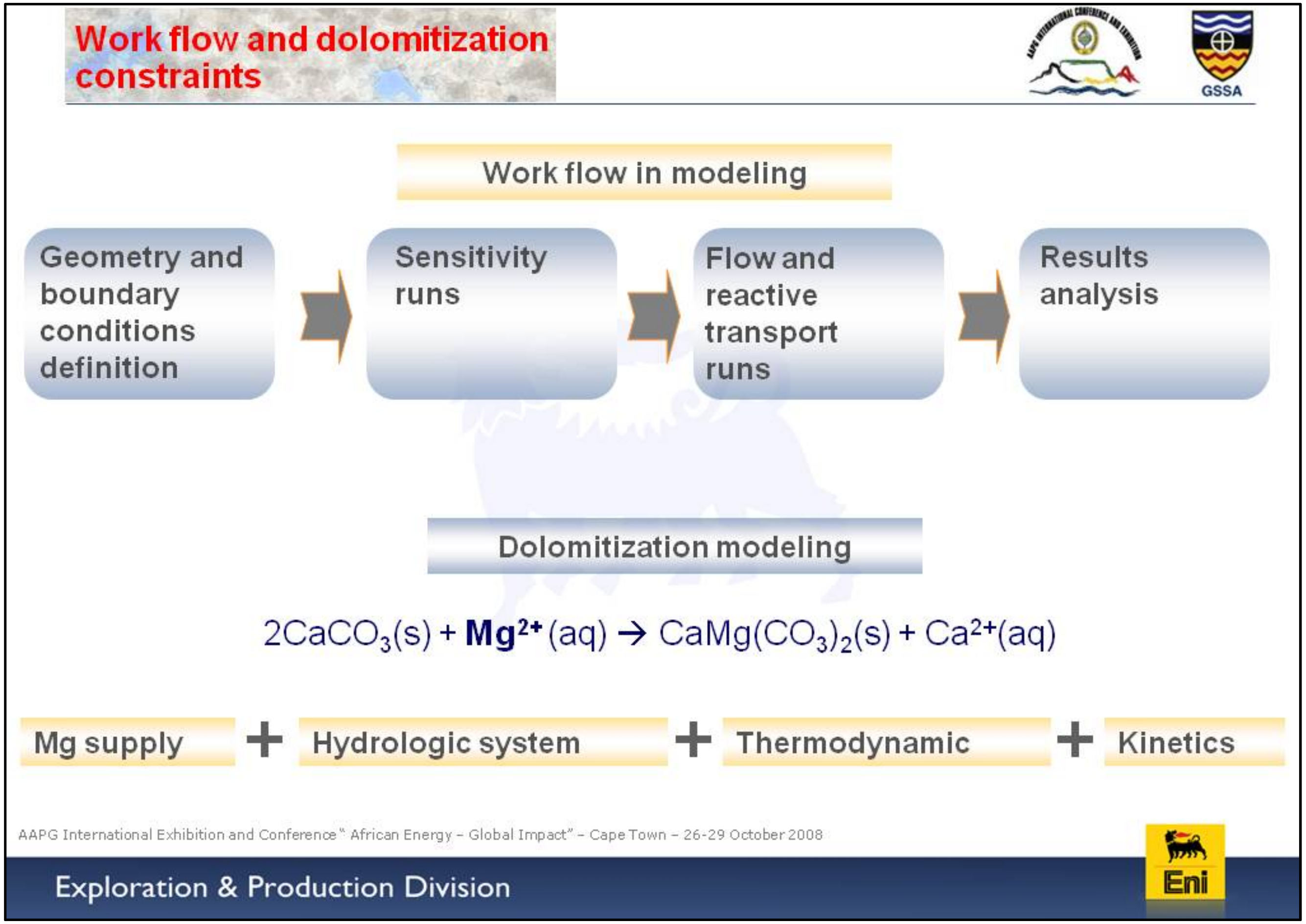
- Brine flux in a porous media
- Transport of chemical species in water solution
- Mineral/fluid reactions

Applications:

- Diagenesis in sedimentary successions
- CO_2 sequestration in reservoir
- H_2S e CO_2 interactions in petroleum systems
- Geothermic
- Waste disposal

Notes by Presenter:

The Reactive transport modelling code we use is the toughreact, which was developed by the Laurence Berkeley University few years ago and was used at first in the field of special waste disposal. The code solves the flux of brine in porous media, the transport of chemical species and the chemical reactions between mineral and fluid. Other applications of this software are……The ones with red dots are those used in oil industry.



Notes by Presenter:

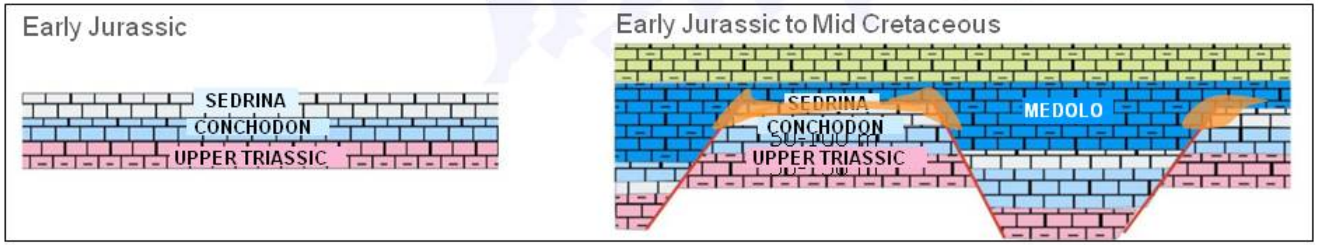
The dolomitization equation, meant as replacement of dolomite after calcite, implies a large amount of Mg introduced into the water-rock system. Every dolomitization model must satisfy several constraints, the most important of which, are: the Mg supply, the hydrologic system, the thermodynamic constraints, and the kinetics factors. The work flow in an application of forward Modelling includes: geometry and boundary conditions of the case that we are going to model. They include many variables that can be evaluated performing sensitivities runs. These variables can be for example fluids chemical composition or petrophysical properties of the rock. After having tested various reactive transport modelling runs we analyses the results and in case of multiple runs we compare the different scenarios.

Content

Compaction dolomitization: Jurassic of Po Plain case history

GSSA

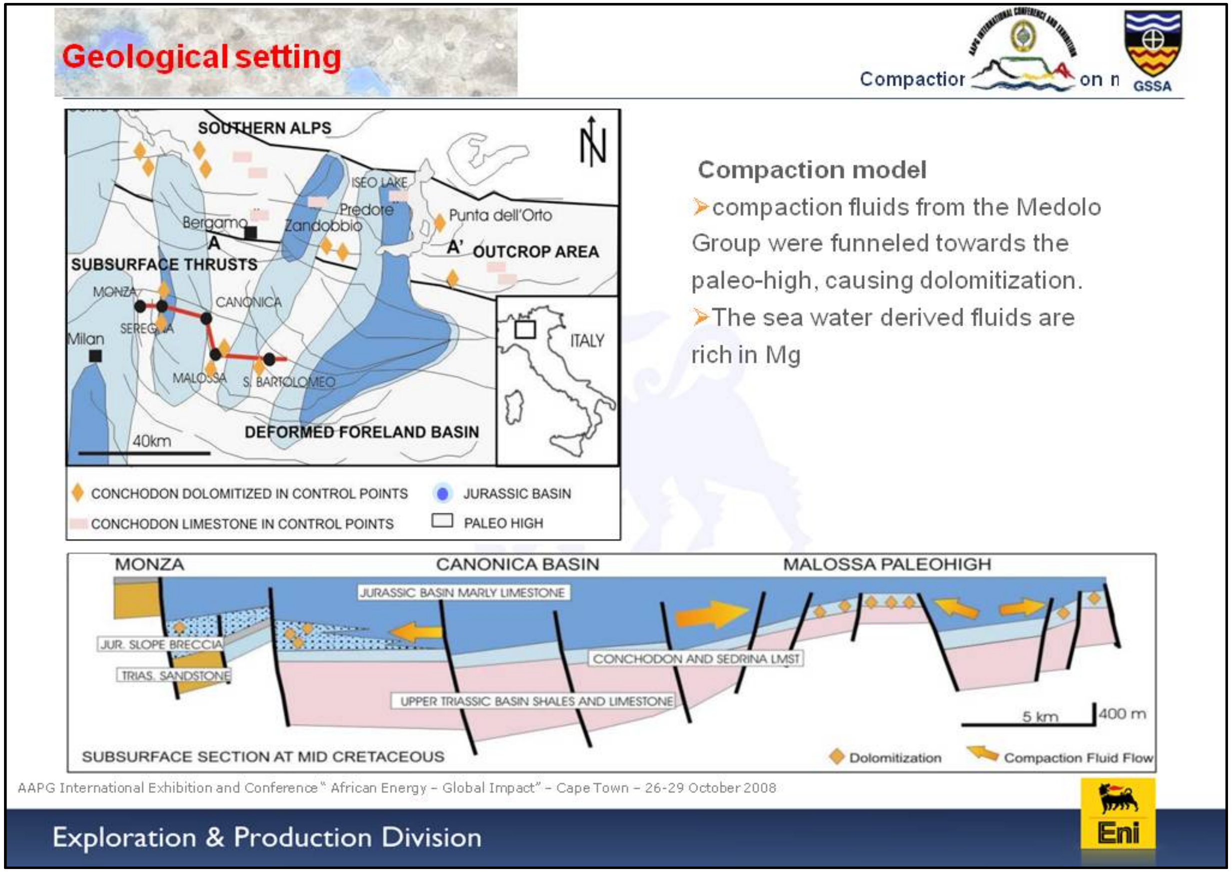
- Location: Southern Alps and Po Plain (Northern Italy)
- Formations: Conchodon Fm (GSRT) and Sedrina Lmst (MDST and WKST)
- Age: Early Jurassic
- Depositional environment: carbonate platform
- Early Jurassic - carbonate platform drowning and deep intra-platform basin formation (Medolo Group)
- Middle Jurassic to Cretaceous - pelagic carbonate basin filling
- Jurassic to Cretaceous - compaction



- Dolomitization on the paleo-highs or on their edges

Notes by Presenter:

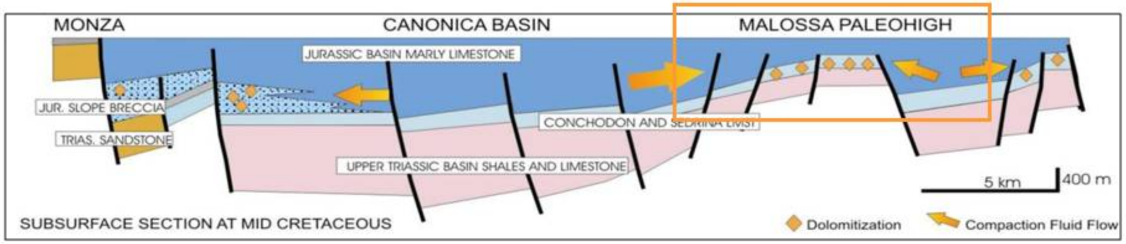
The studied dolomite bodies are located in Northern Italy, both in the Southern Alps and in the foreland basin Po Plain. The dolomitization affected the Conchodon and Sedrina carbonate platforms of Early Jurassic age. During Pliensbachian, the large carbonate platform drowned and intraplatform basins were formed and filled by pelagic carbonates of Medolo Group. The pelagic carbonate deposition went on till mid-Cretaceous. During that period the Medolo carbonate underwent compaction. The dolomitization is pervasive in the small paleohighs and is present on the edges of large ones.



Notes by Presenter:

In this map you can see the lateral extension of the deep basin: in darker blue the depocenter areas, in pale grey the paleohighs. The rhomb's and the squares indicate the mineralogy of the underlying Conchodon Formation in the control points (both outcrop and subsurface): the rhomb's indicate the dolomitization patches while the other symbol Indicate the limestone. In the cross section in Po Plain, we can see the Malossa paleohigh bounded by two basins: you'll note that he dolomitization is confined in the paleohigh and in the breccia wedges in the western part of the Canonica Basin. The dolomitization interpretation is based on a large amount of analytical data, form geochemical to petrographic ones, and on outcrop evidences. The proposed model is that of <<compaction driven dolomitization>>: the dolomititizing fluids expelled from the basin during compaction fluxed and funneled into the isolated paleohighs made of porous limestone causing dolomitization.

Conceptual model



The numerical modeling was aimed to reproduce the compaction dolomitization in the Malossa paleohigh

Questions to be answered by numerical modeling

- is the **conceptual model realistic** in terms of chemio-physical constraints?
- which are the main **parameters/constraints** that guided the dolomitization patterns?
- did the geological constraints allow a **complete dolomitization** of the paleohigh?
- **can we predict the distribution** of dolomitization in the different paleogeographic areas?

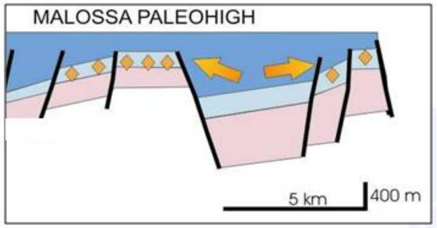
Notes by Presenter:

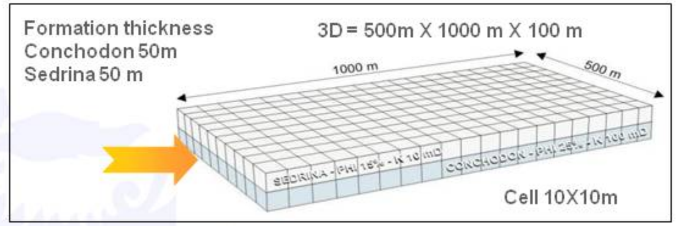
The numerical Modelling was aimed to reproduce the compaction driven dolomitization process in Malossa paleohigh. Specifically we addressed the following questions:

- Is the conceptual model realistic in terms of chemio-physical constraints?
- Which are the main parameters that guided the dolomitization pattern observed in outcrop?
- Did the geological constraints (compaction fluid and paleohigh volumes ratio) allow a complete dolomitization of the paleohigh?
- Can we predict the distribution and qualitative amount of dolomitization in the different paleogeographic areas?

Geometry and boundary conditions

Geometry simplificaton





Geological parameters

- Mineralogy 99% calcite
- Temperature 35°C
- Pressure 45 bar
- Conchodon PHI 25% K 100mD
- Sedrina PHI 15% K 10 mD
- Duration about 20 My

Parameters Subject to Sensitivities

- Fluid composition

sea water modified, after Berner 2004

Parameters to be calculated

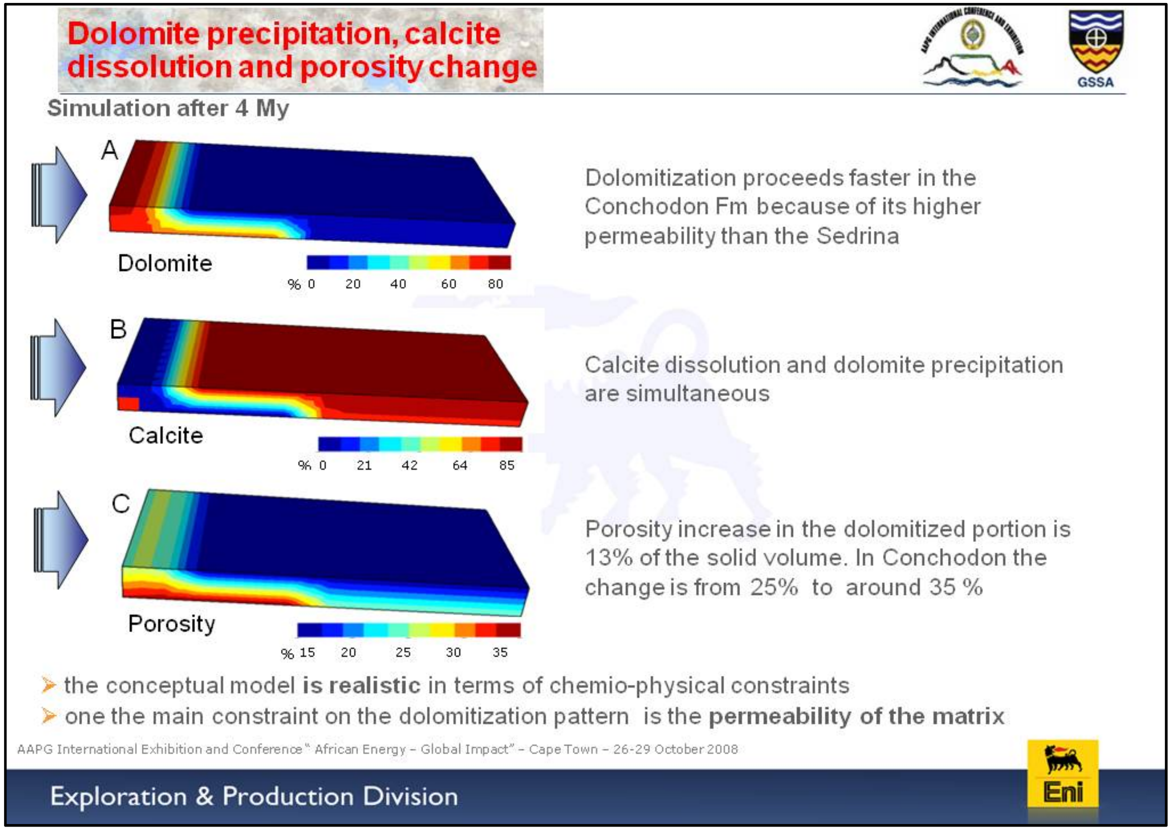
- Compaction Fluid flow through basin simulation

Flow rate into the paleo-high up to **31 km/My** (considering funneling along faulted blocks)

Notes by Presenter:

In this slide we have summarized the geometry and boundary conditions of the simulations. First of all the actual geometry is simplified: we simulate one of the blocks of the paleohigh, bounded by faults. The block is 500 m wide, 1000 m long and 100 m thick being each formation about 50 m thick. The finer grid used has of 10 by 10 meter cells. The geological parameters include initial mineralogy that is calcite, the temperature, pressure and porosity and permeability of the formations at the time of the compaction and dolomitization. The fluid composition is an unknown value and for this we performed simulations using different compositions and here we present the results of the simulation with sea water with MgCa ratio estimated for Jurassic from literature.

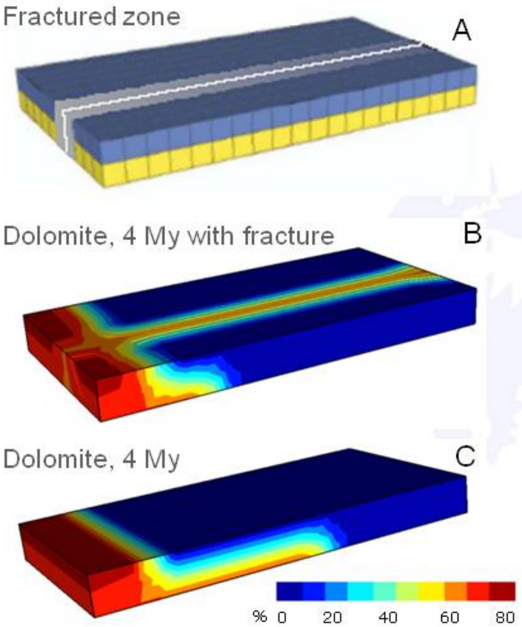
Another sensible parameter is the fluid flow rate: this is derived from the geological case using a specific basin modelling simulator.



Notes by Presenter:

Using the parameters illustrated in the previous slide the simulation reproduced the dolomitization with the following characteristics: In diagram A is evident that the dolomite front advancement faster in the Conchodon Formation than in the Sedrina one because the Conchodon is more permeable. In diagram B the calcite dissolution is shown: comparing the calcite dissolution and the dolomite precipitation fronts we observe/ you will note that the two processes are simultaneous. In diagram C the rock porosity distribution suggests that the dolomitization process is accompanied by an increase of porosity of 13% of the rock volume. The first question is answered: the chemio-physical conditions allowed the dolomitization: the compaction driven dolomitization was possible. Therefore to assess better the process we'll see the sensitivities on the water composition based on 3D thin grid. Moreover we answered partly to the second question: one of the parameters that influence the dolomitization rate is the matrix porosity/permeability. To better assess the effect of permeability we considered a block with a fracture zone….

Fractured zone: effects on dolomitization pattern

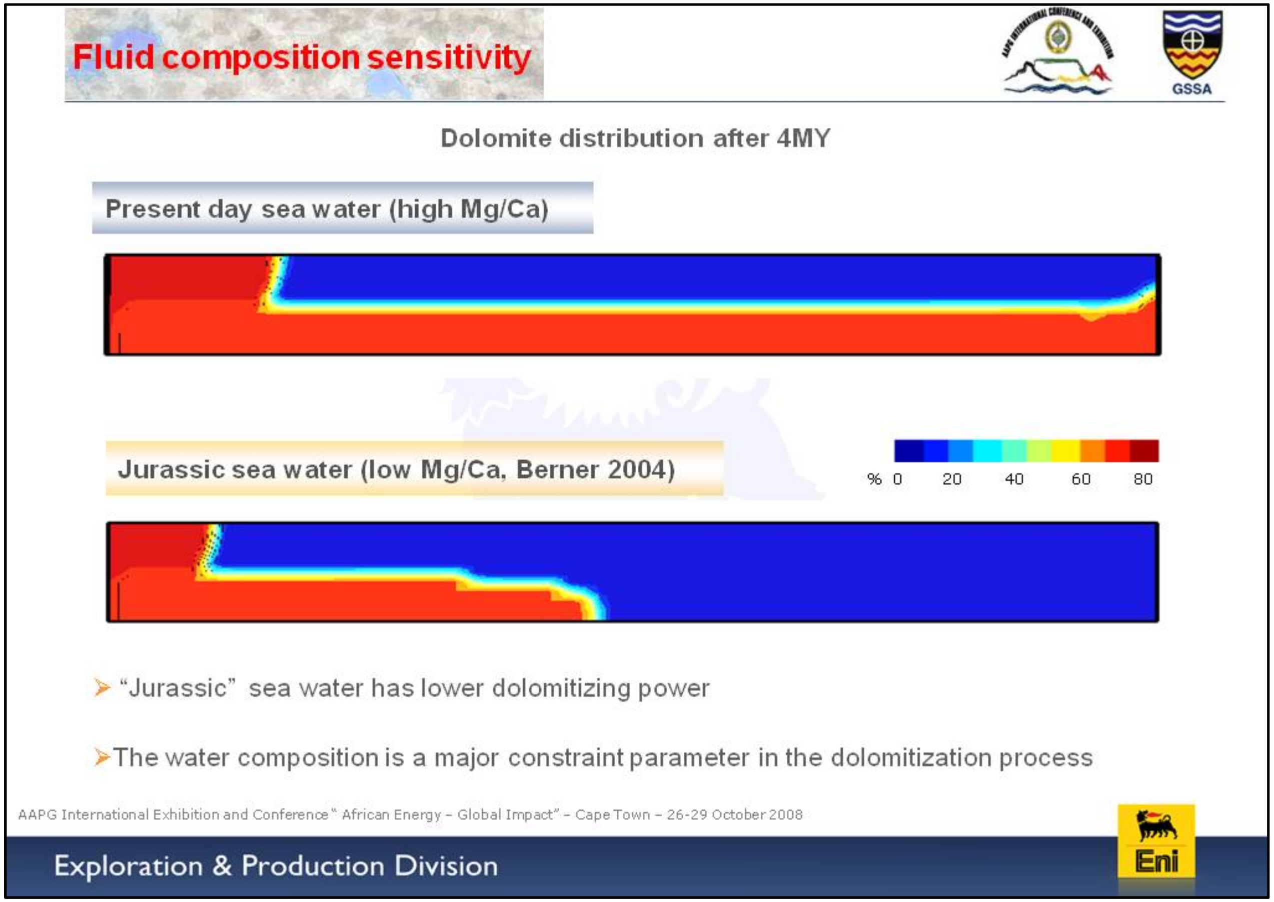


- The fractured zone funnels the fluids and the matrix dolomitization slows down.
- Dolomitizing fluids escape the system, allowing dolomitization in permeable layers lateral or above the Sedrina/Conchodon Fms

- high permeability zones drive the dolomitization pattern/geometry

Notes by Presenter:

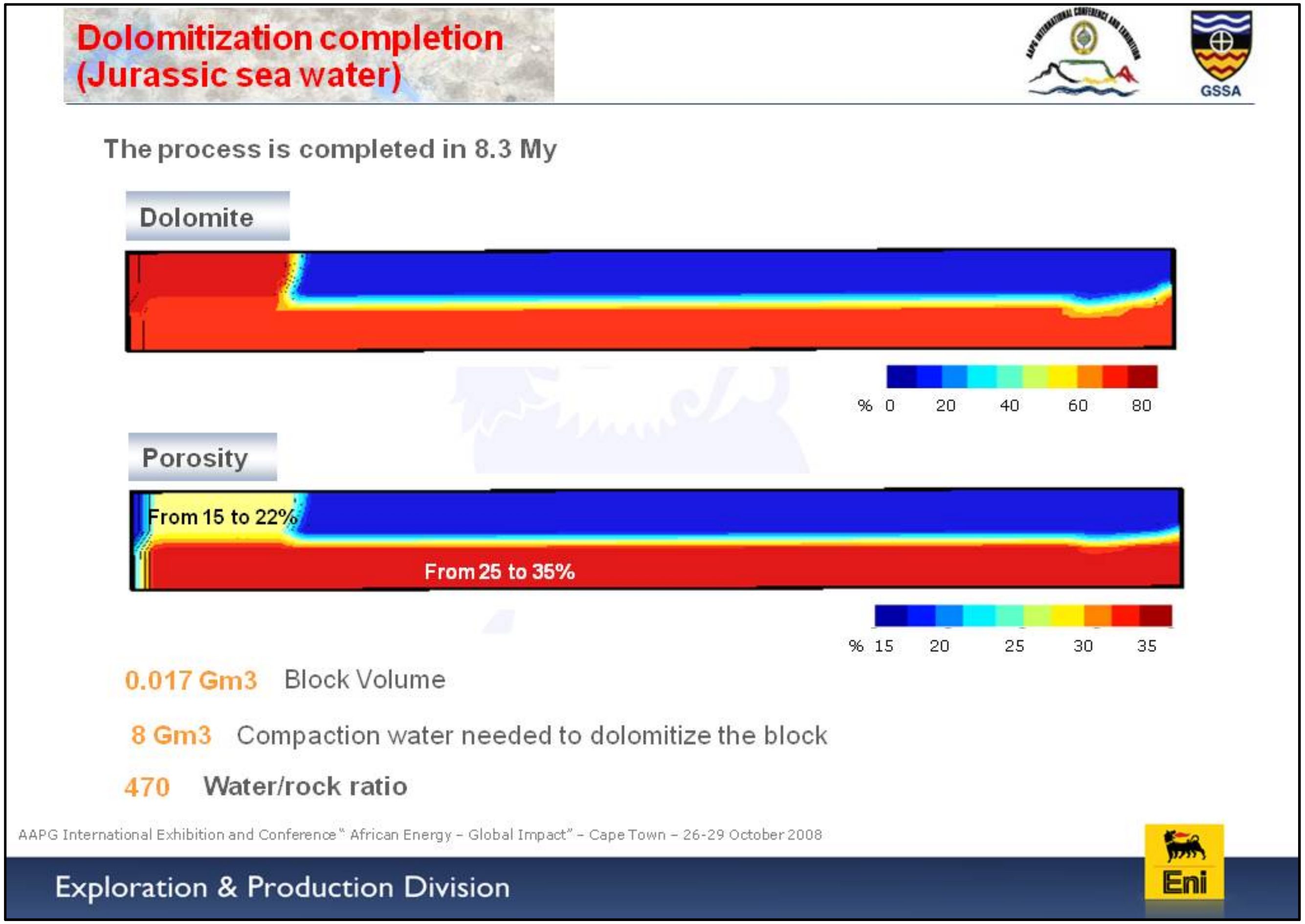
In this block we inserted a fractured zone as displayed in diagram A. In presence of a fractured zone, after 4MY the dolomite front is further back than in the case of the homogeneous block: part of the dolomitizing fluids escaped the matrix funnelling through the fracture. This has also other 2 effects: the walls of the fracture are dolomitized and the fluids can have gone to dolomitize other zones outside the system. This effect was observed in the outcrop. Meters above the dolomitized Conchodon we can have dolomite along faults in younger formations. We have another answer to the second question: high permeability zones like major faults may guide dolomitization and therefore dolomite body geometries.



Notes by Presenter:

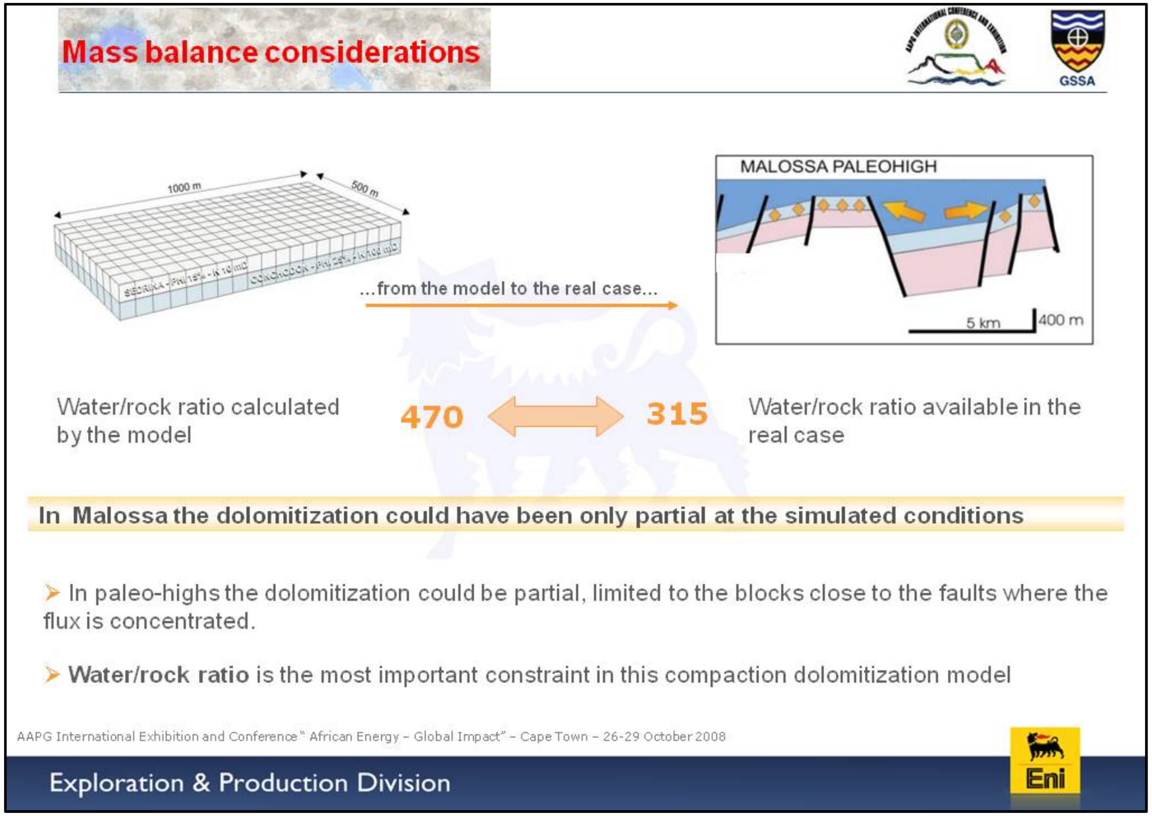
As anticipated, an important input parameter is the composition of the compaction fluids.

The compaction fluids are of sea water origin, as a first approximation the present sea water, can be used. Another water was considered, closer to the Jurassic sea water composition, using a lower Mg/Ca ratio according data from Berner 2004. So we compared the simulation conducted with the two fluids called present day and Jurassic waters. In the pictures we observe the dolomitization front after 4 MY in the case the Jurassic sea water is further back than in the case of present day sea water. This sensitivity highlighted the water composition as a major constraint of the in the dolomitization process.



Notes by Presenter:

To summarize the results of the final simulation we can look at the diagrams: The complete dolomitization occurred in 8.3 My in the Conchodon Dolomite, while in the Sedrina formation the dolomitization ceased in less than one third section close to the inflow. The porosity increased in the dolomitized section: Conchodon passed from 25 to 35% and Sedrina from 15 to 18%. To dolomitize the block we fluxed 8 Giga cubic meters and being the block of 0.017 Giga cubic meters the water/rock ratio was of 470. This value is of the same order of magnitude of that reported in the literature (by Land (1985) and Machel (2004)). This ratio should be verified in the geological situation too…..



Notes by Presenter:

In this slide we compare the water/rock ratio of the simulated block and the real geological case obtained by the basin modelling simulation. In Malossa, the basin modelling calculated the volume of water expelled from the basin and the volume of the carbonate paelohigh: the water/rock ratio is only 315. 315 is 30% lower than that calculated by the simulation: this suggests that the dolomitization of the Malossa paleohigh could have been only partial with the used chemio-physical constrains.

So another important constraint was evaluated: the rock/water ratio limits the dolomitization in the compaction model, even if the other constraints are fulfilled.

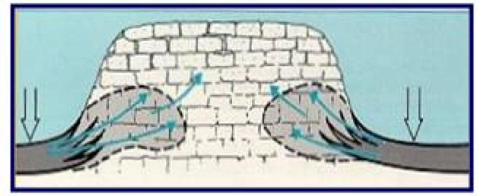
This mass balance exercise answered another initial question: the dolomitization can be incomplete in large paleohigh and depends on the volume of the basin respect the volume of the paleohigh.

Content

1. Introduction
2. Toughreact principles and work flow
3. Compaction dolomitization: Jurassic of Po Plain case history
4. Conclusions

Conclusions

➢1. is the conceptual model realistic in terms of chemio-physical constraints?



THE COMPACTION-DRIVEN MODEL EXPLAINS THE OBSERVED DOLOMITIZATION PATTERN

➢2. which are the main parameters that guided the dolomitization pattern?

- PERMEABILITY OF THE MATRIX
- HIGH PERMEABILITY ZONES
- WATER COMPOSITION
- WATER/ROCK RATIO

➢3. did the geological constraints allow a complete dolomitization of the paleohigh?

THE MASS BALANCE CALCULATIONS INDICATE THAT THE DOLOMITIZATION COULD NOT BE COMPLETE IN THE PALEOHIGH

The paleohigh was dolomitized selectively in the zones close to the faults or in more permeable matrix zones …

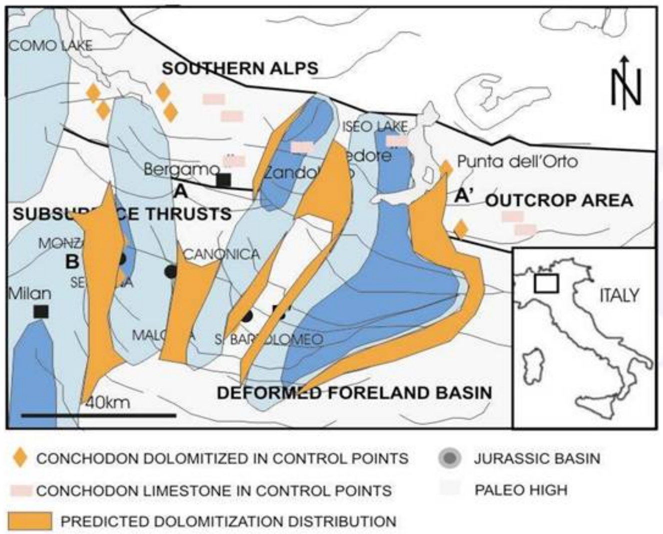
Notes by Presenter:

The first question whether the compaction model was efficient was answered positively.

Moreover we have examined various constraints that guided the dolomitization process, namely, leggerli.

Conclusions

➤4. How can we predict the distribution of dolomite bodies?



➤THE MAIN CONSTRAINT IS THE BASIN/PLATFORM VOLUME RATIO

➤THE SMALLER THE PALEOHIGH THE HIGHER THE DOLOMITIZATION VOLUME

➤IN LARGE PLATFORMS THE DOLOMITIZATION WILL BE LIMITED TO THE SLOPE BRECCIA EDGES AND PLATFORM MARGINS

Notes by Presenter:

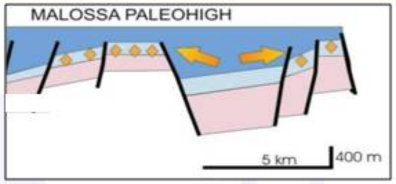
The last question was about the prediction of the distribution of dolomite bodies in the subsurface. We have seen that the main constraint is the water/rock ration that corresponds to the basin/platform volume ratio. This means that the smaller the paleohigh with respect to the basin the higher will be the dolomitized volume. Moreover in a large platform the dolomitization will be limited to the slope breccia and the edges of the platform facing the basin.

In this map, in orange we can see the inferred distribution of dolomitization. This map suggests the distribution of the potential dolomitized reservoir in the subsurface and can be used in the hydrocarbon exploration phase.

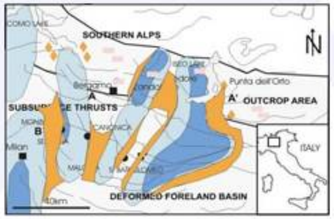
Conclusions
Modelling goals

The three main benefits of the modeling application have been obtained

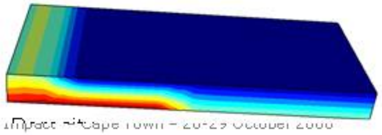
VERIFICATION OF HYDROLOGY, MASS BALANCE, THERMODYNAMICS, KINETICS



SPATIAL EXTRAPOLATION OUTSIDE THE INVESTIGATED AREA



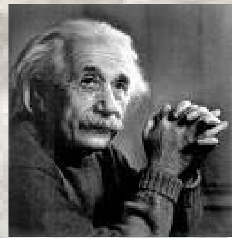
POROSITY VARIATIONS CALCULATIONS



Notes by Presenter:

- In the examples of dolomitization simulations the three main purposes of the numerical modelling have been fulfilled.
- The three models of dolomitization were proven valid for the considered case histories.
- In the both carbonate systems insights of distribution of dolomite and related increased porosity were derived.
- Calculation of the amount of porosity enhancement was done.

Acknowledgements



"Make your theory as simple as possible, but no simpler." A. Einstein
"For every complex question there is a simple and wrong solution." A. Einstein.

Ockham's Razor: A rule in science and philosophy stating that entities should not be multiplied needlessly.
This rule is interpreted to mean that the simplest of two or more competing theories is preferable and that an explanation for unknown phenomena should first be attempted in terms of what is already known.

Acknowledgements

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We also thank all the people who participated in the production of the input data for the modeling.

Selected References

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